Enhancing Power Harvesting Using a Tuned Auxiliary Structure

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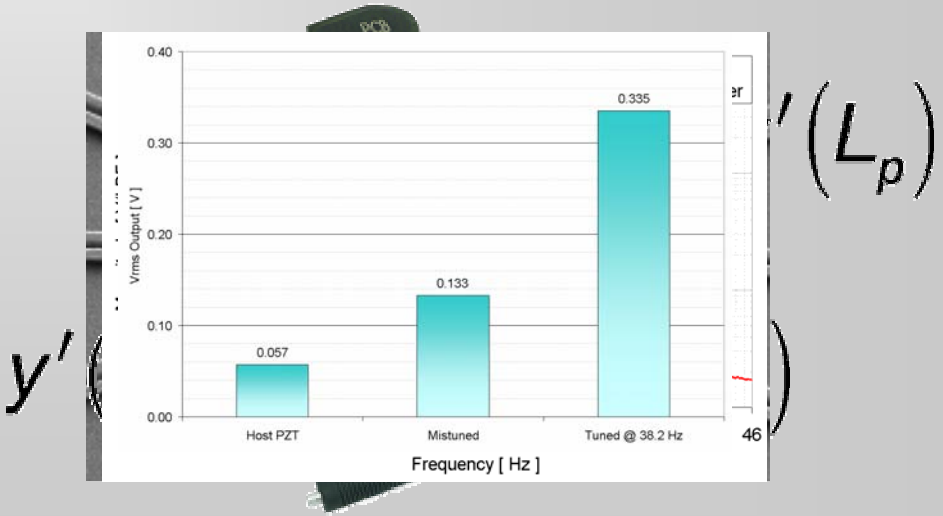
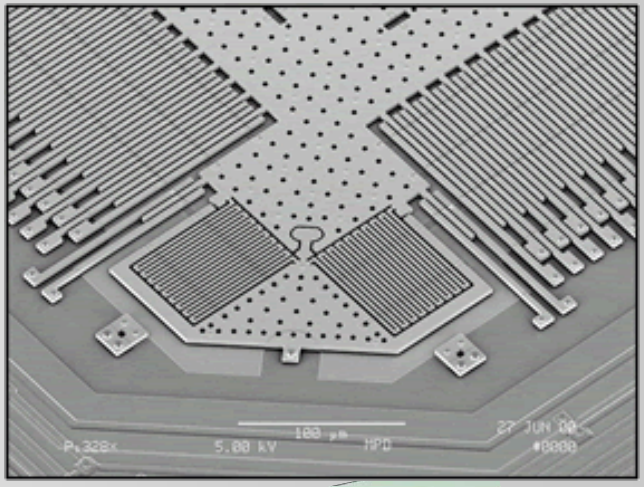
Overview

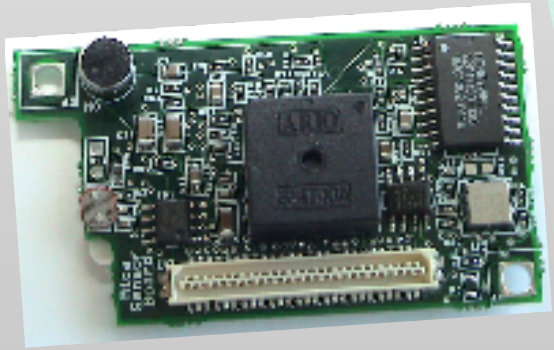
- Motivation
- Theory
- Approach/Experimental Setup
- Tuning Procedure
- Experimental Results
- Conclusions and Recommendations

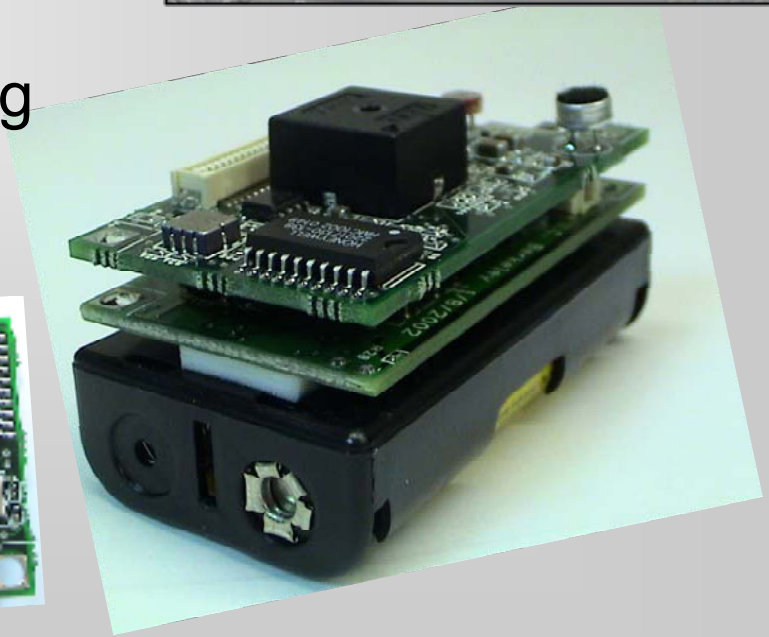


Energy harvesting is the key to self-sufficient microelectronic devices



- Wireless communications devices
- Digital signal processes
- Wireless sensors
  - Structural health monitoring
  - Damage prognosis





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The Theory

because knowing is half the battle

Voltage applied to PZT element:

Its dimension will change

A PZT element is mechanically stressed:

It generates electrical charge

Vibration → PZT deformation & stress → Electrical charge → Power generation

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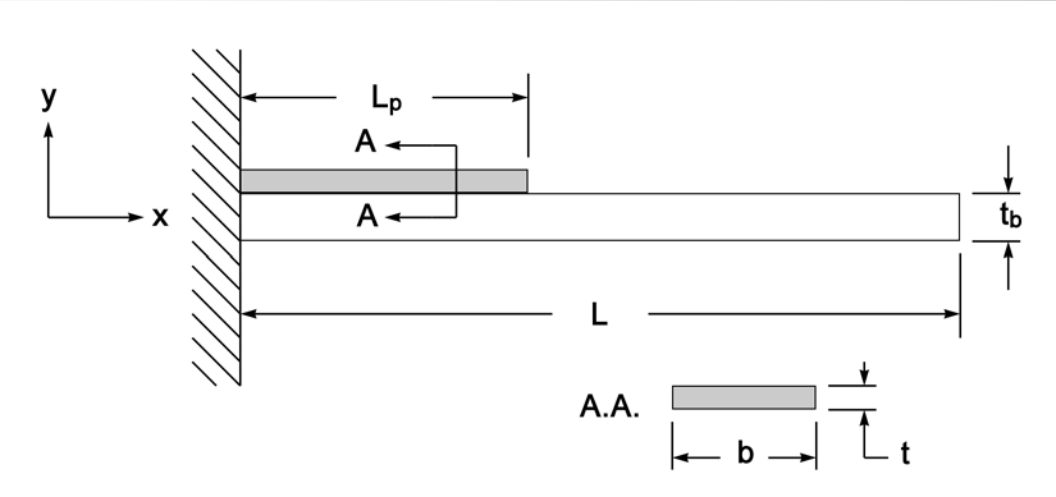
Voltage is related to the physical properties of the PZT



$$V_{out}(t) = \frac{q}{C_p} = K_s y'(L_p)$$

K_s = electrical & physical properties of the PZT

$y'(L_p)$ = slope of the auxiliary structure at the end of the PZT patch.

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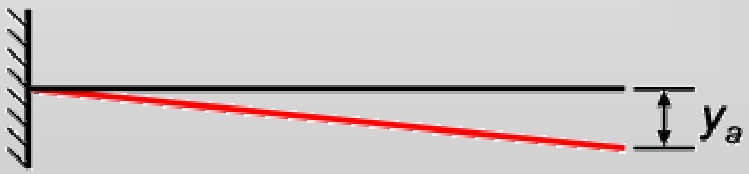
The auxiliary structure is tuned to its first bending mode

Let's write the slope in terms of tip displacement,

$$y'(x) = \frac{3y_a}{2L^3}\left(2Lx - x^2\right)$$



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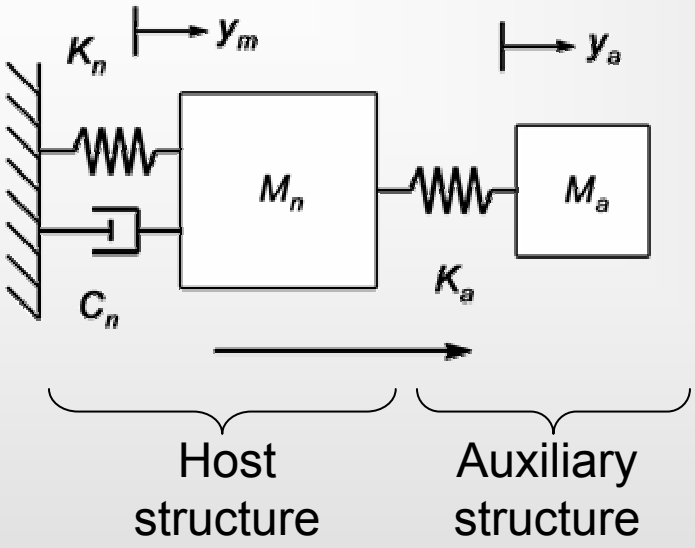
The motion of the coupled host structure and PZT can be expressed as a 2-DOF linear system



$$M_a\ddot{y}_a + K_a y_a - K_a y_m = 0$$

$$M_n\ddot{y}_m + C_n\dot{y}_m + K_n y_m - K_a y_a = \phi_{na}\phi_{nk}F$$

Note: we assume negligible damping in the auxiliary structure

$$\begin{bmatrix} Y_m \\ Y_a \end{bmatrix} = \frac{\begin{bmatrix} K_a - M_a\omega^2 & K_a \\ K_a & K_n + K_a - M_n\omega^2 + j\omega C_n \end{bmatrix}}{\Delta(\omega)} \begin{bmatrix} \phi_{na}\phi_{nk}F(\omega) \\ 0 \end{bmatrix} = \begin{bmatrix} \dfrac{K_a - M_a\omega^2}{\Delta(\omega)}\phi_{na}\phi_{nk}F(\omega) \\ \dfrac{K_a}{\Delta(\omega)}\phi_{na}\phi_{nk}F(\omega) \end{bmatrix}$$

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Assume the auxiliary structure is perfectly tuned to its host structure:

$$y_a = \frac{-\phi_{na}\phi_{nk}F}{K_a} = \frac{-\phi_{na}\phi_{nk}FL^3}{3EI}$$

$$y'(x) = \frac{3y_a}{2L^3}\left(2Lx - x^2\right)$$

$$V_{out}(t) = \frac{q}{C_p} = K_s y'(L_p)$$

$$V_{out}(t) = \frac{K_s\phi_{na}\phi_{nk}F}{2EI}\left(2LL_p - L_p^2\right)$$

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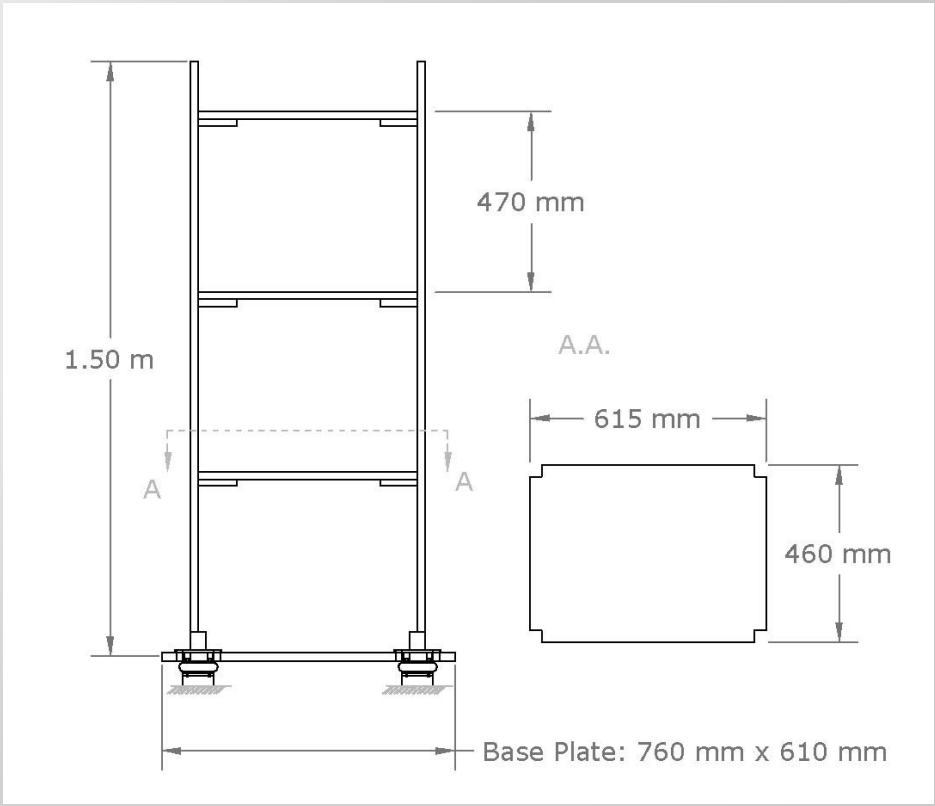
Approach/Experimental Setup

What are we harvesting energy from??



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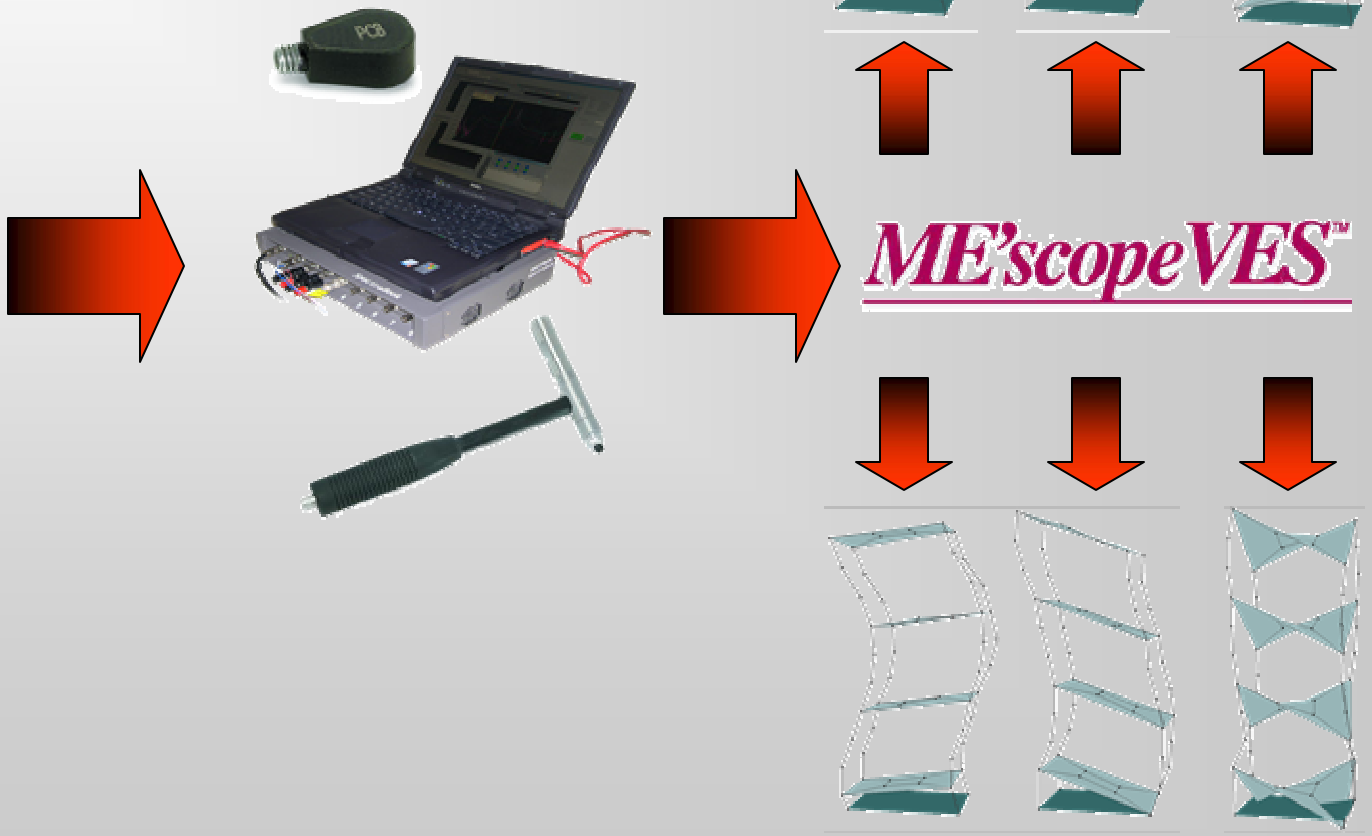
Experimental Setup

Learning the dynamic characteristics of our host structure



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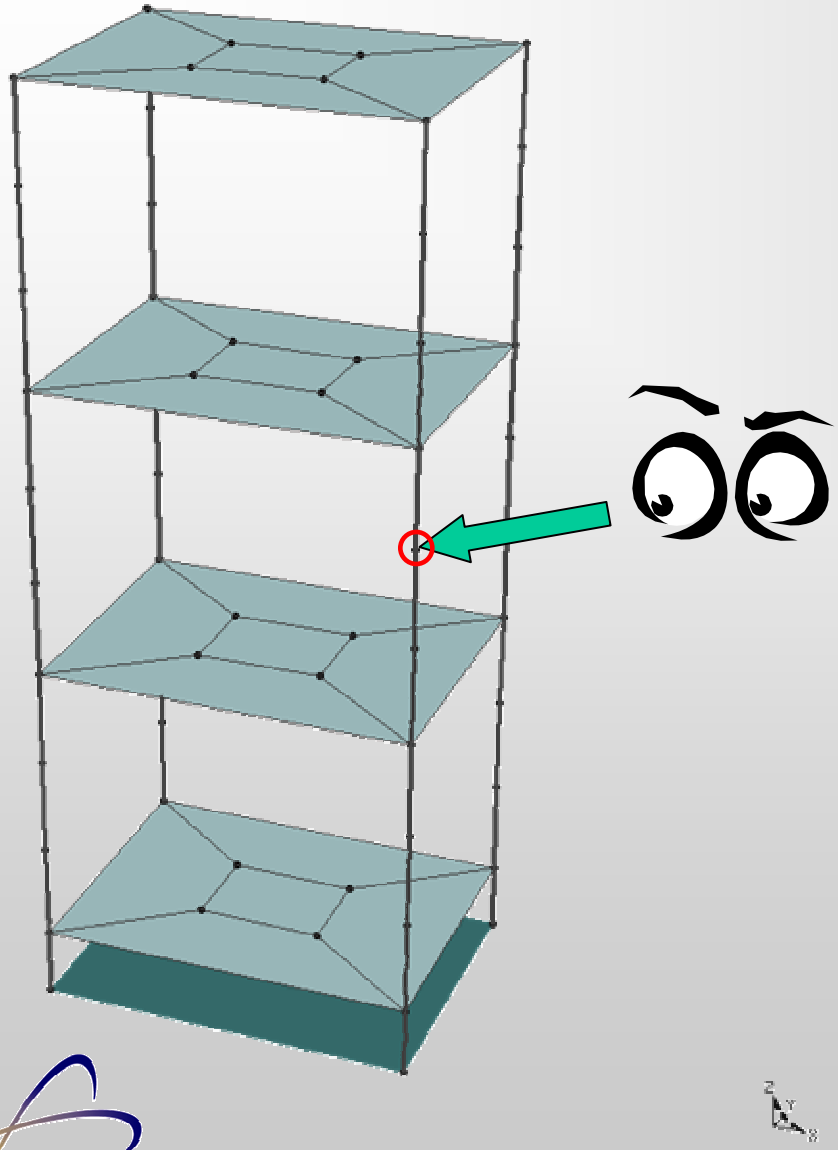
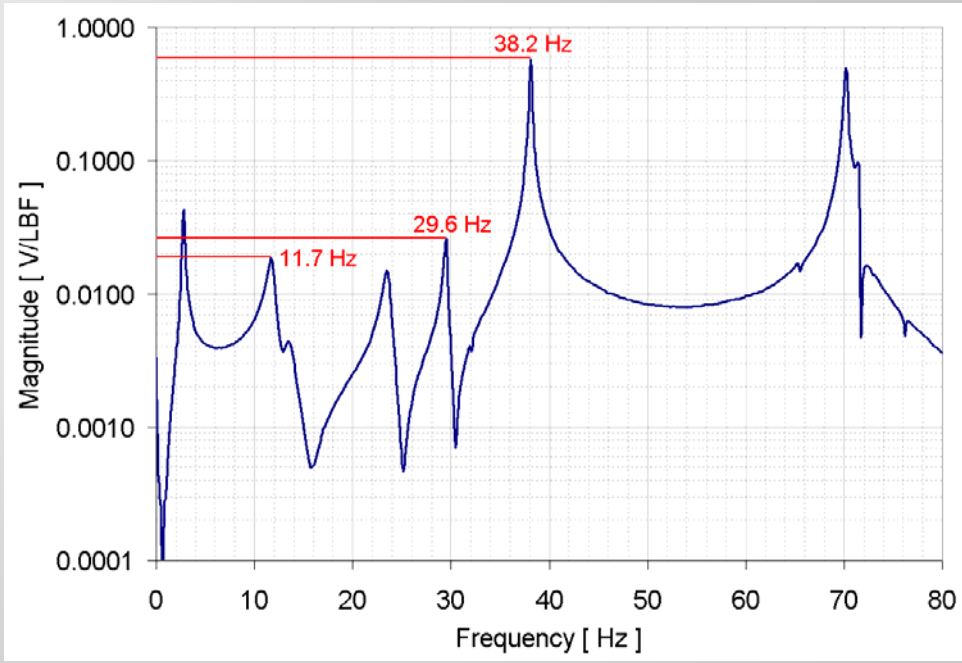
The Tuning Procedure

What Location? What Frequency?





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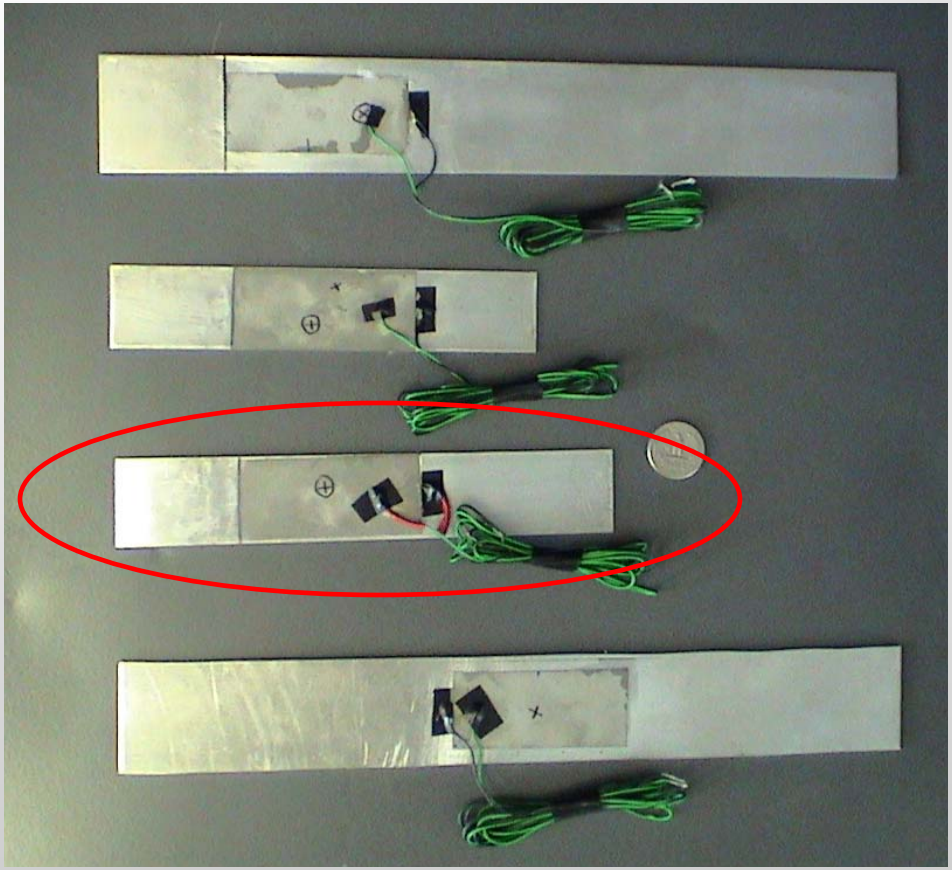
Sample auxiliary structures



$$f_1 = \frac{1}{2\pi}\sqrt{\frac{3EI}{L^3\left(M + 0.24M_b\right)}}$$

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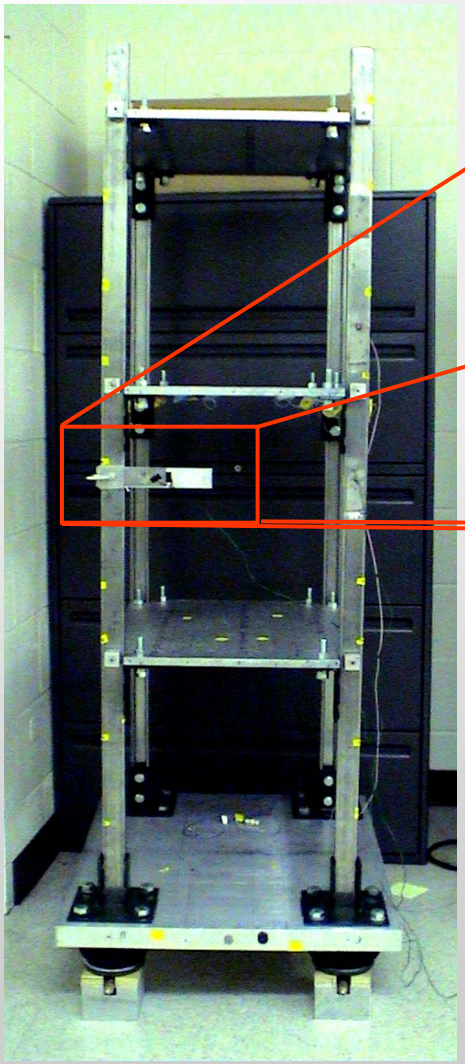
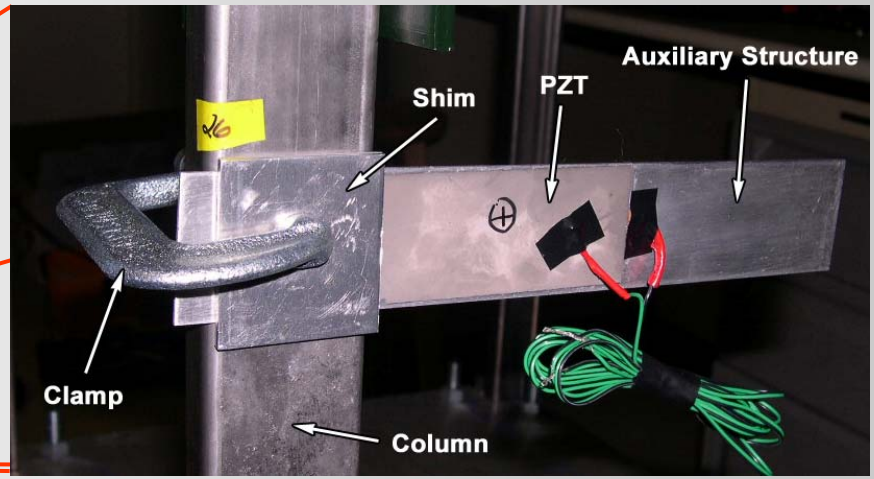
Mounting the Auxiliary Structure…





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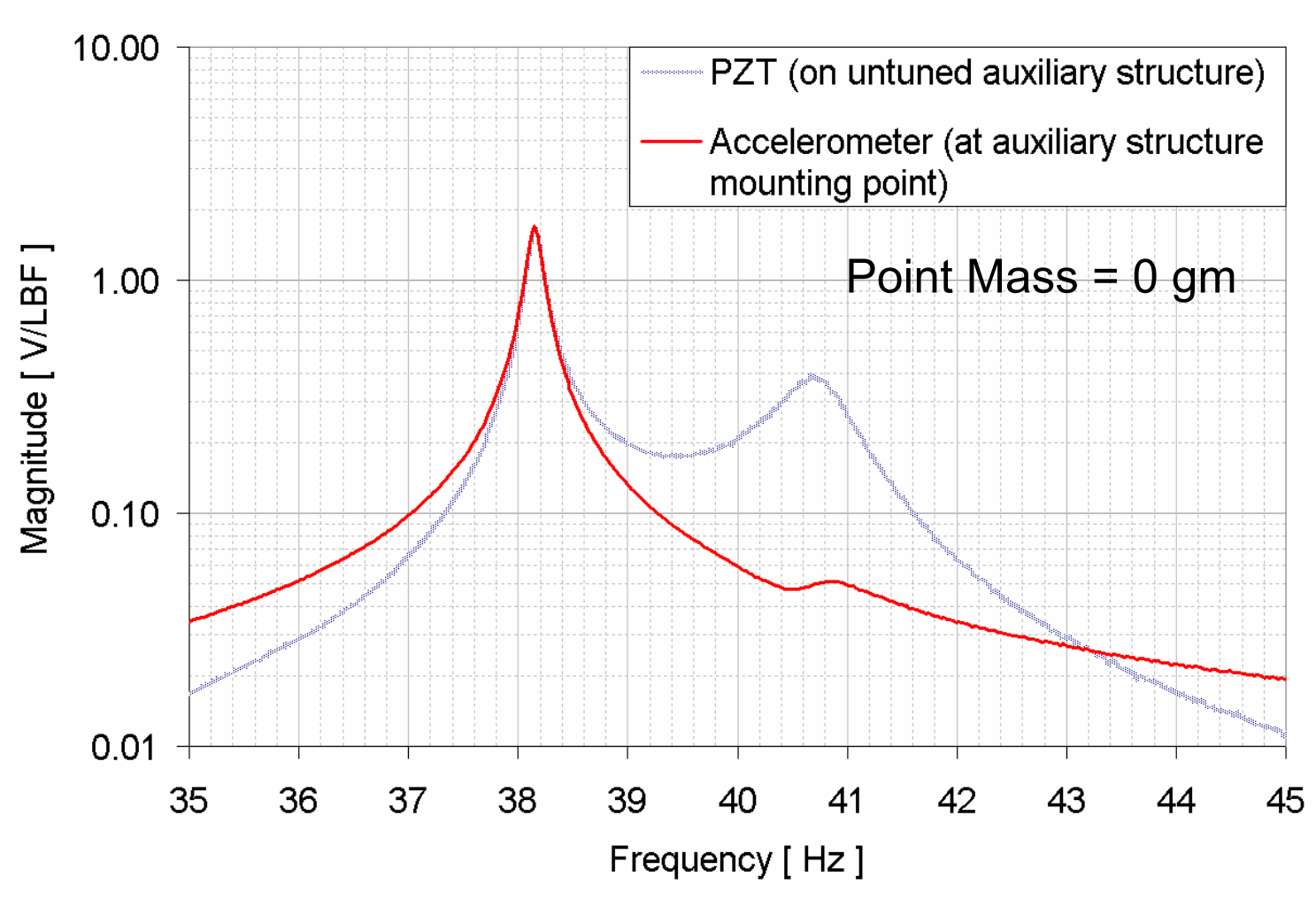
Iteration #1



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B

A

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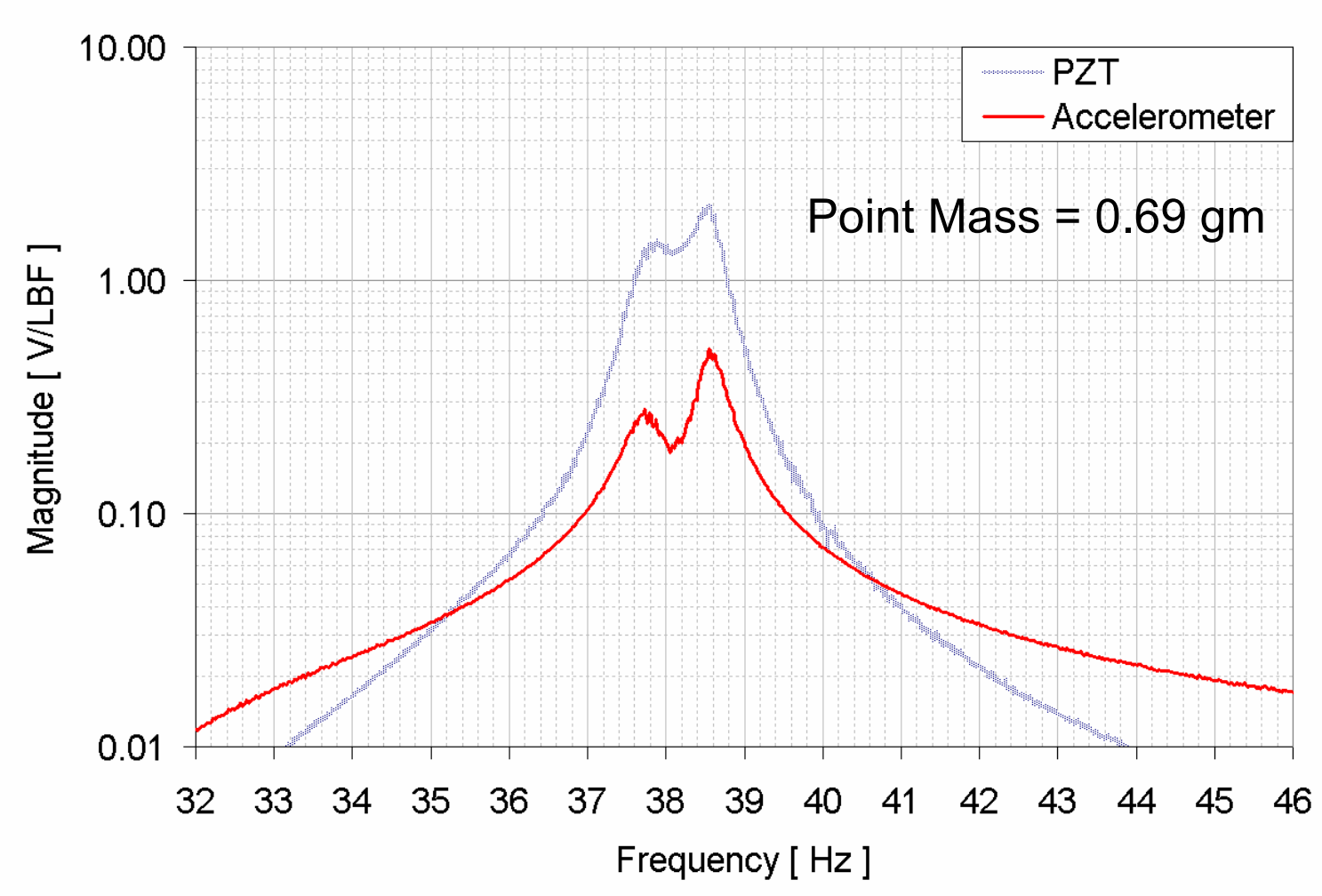
Iteration #3



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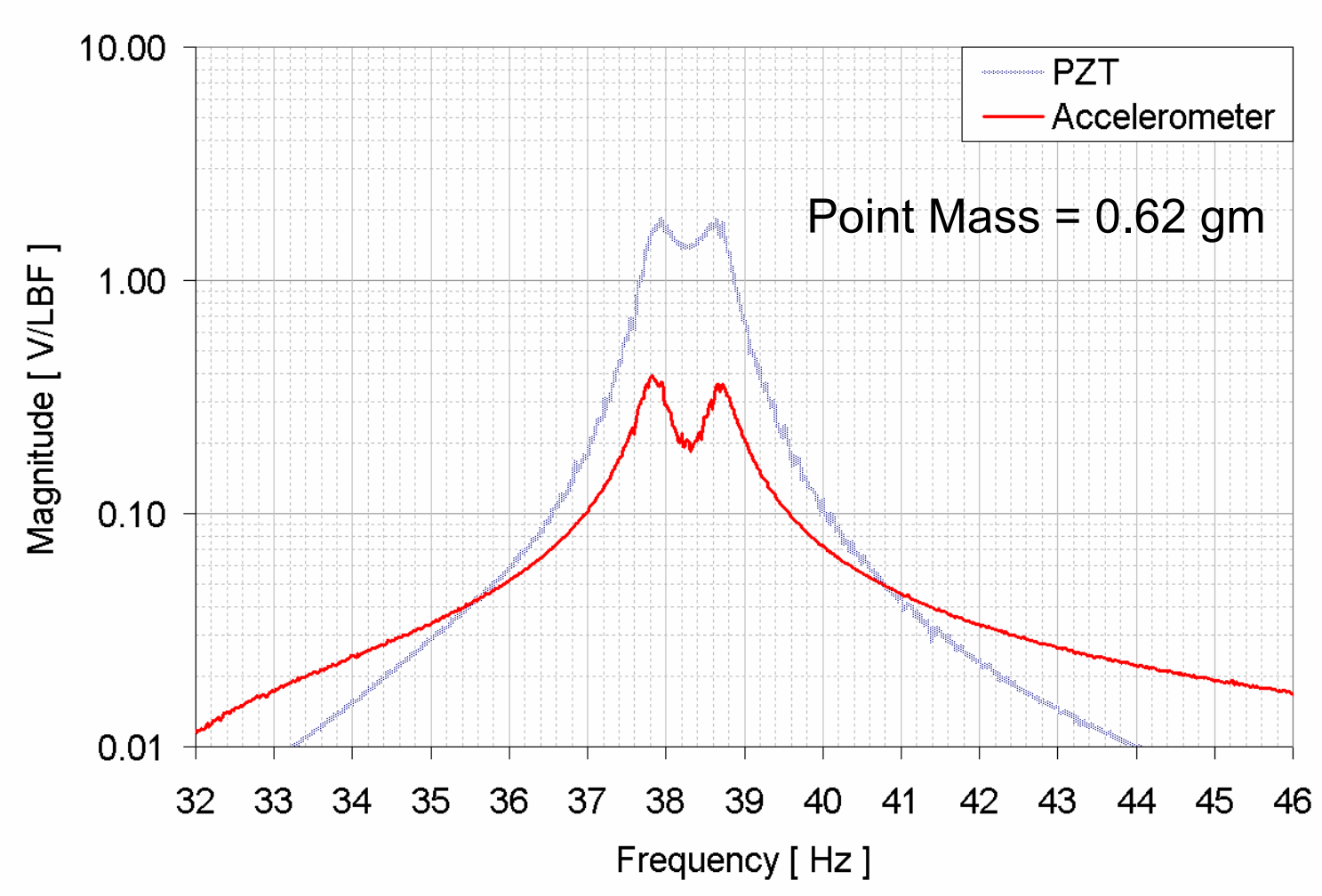
Iteration #5



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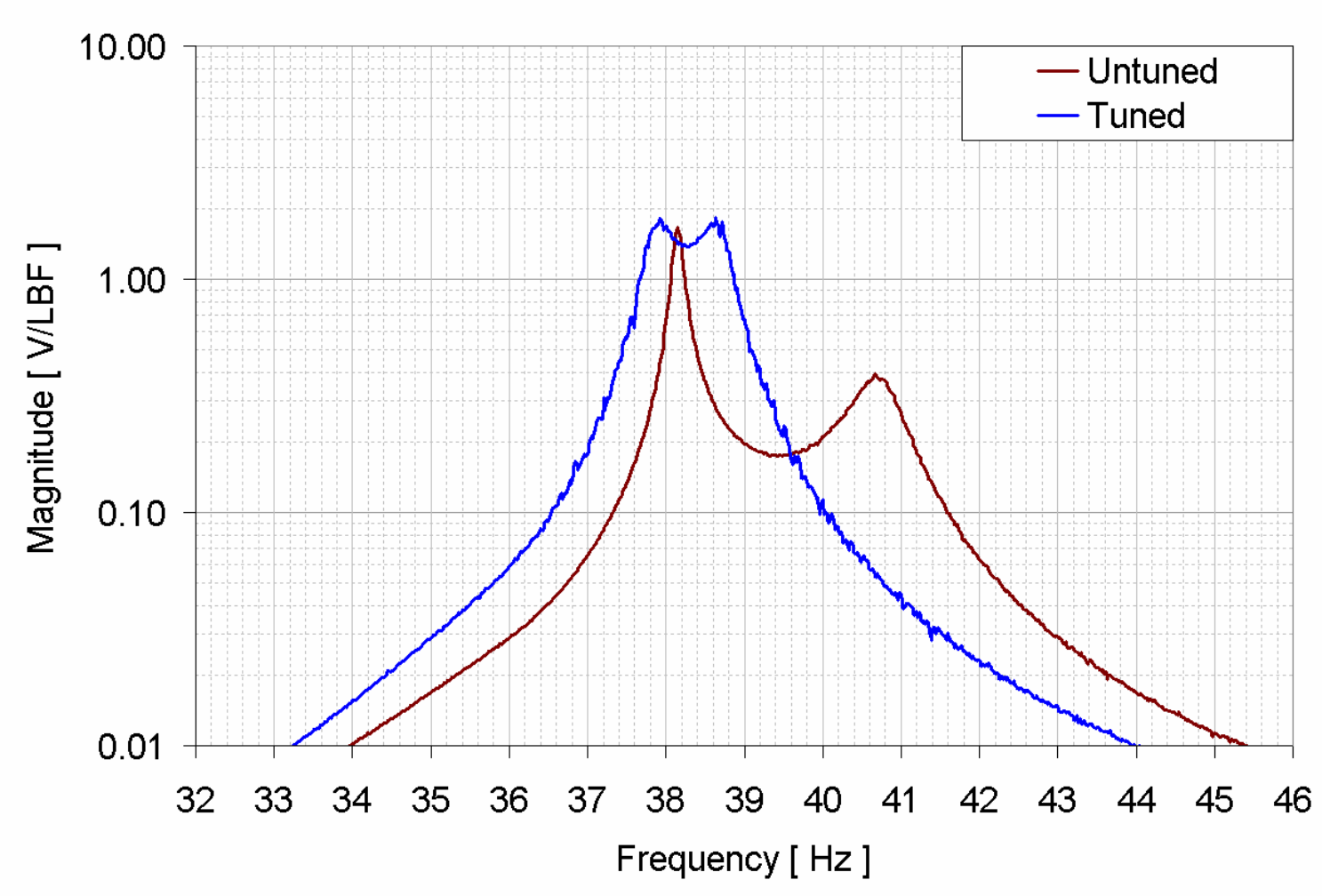
Tuned and Mistuned PZT FRFs



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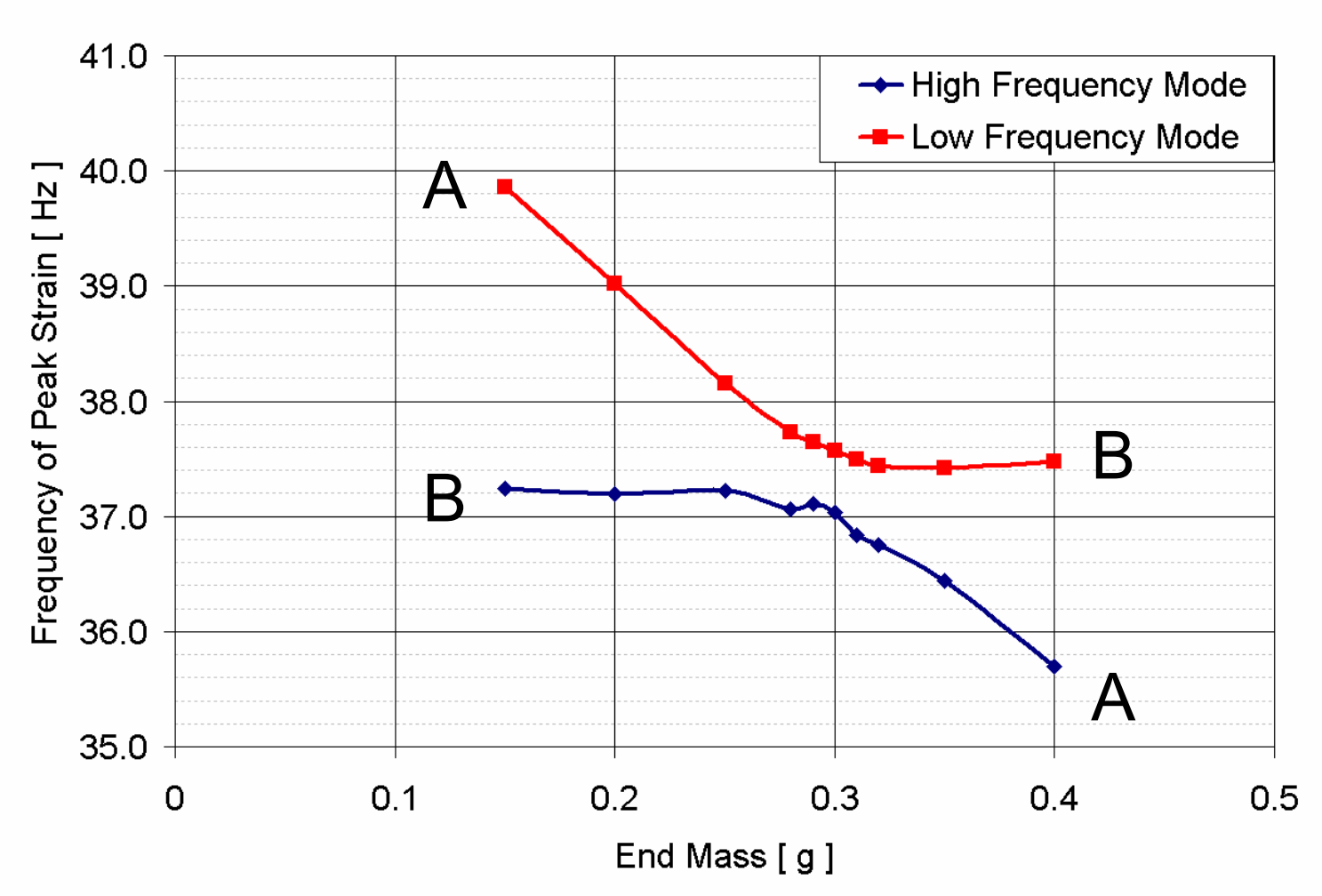
FRF peaks do NOT merge



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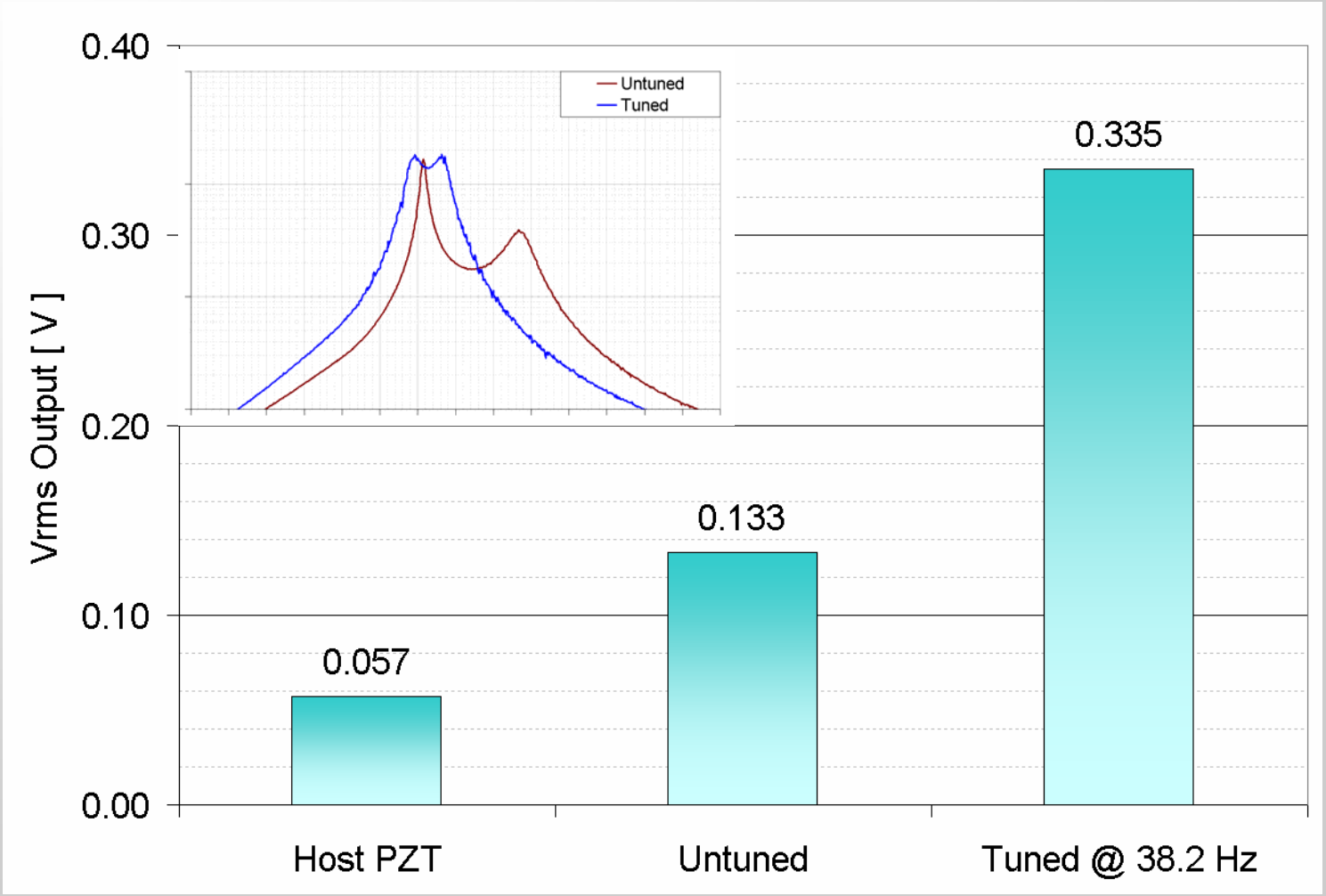
A tuned auxiliary structure demonstrates increased open-loop voltage output



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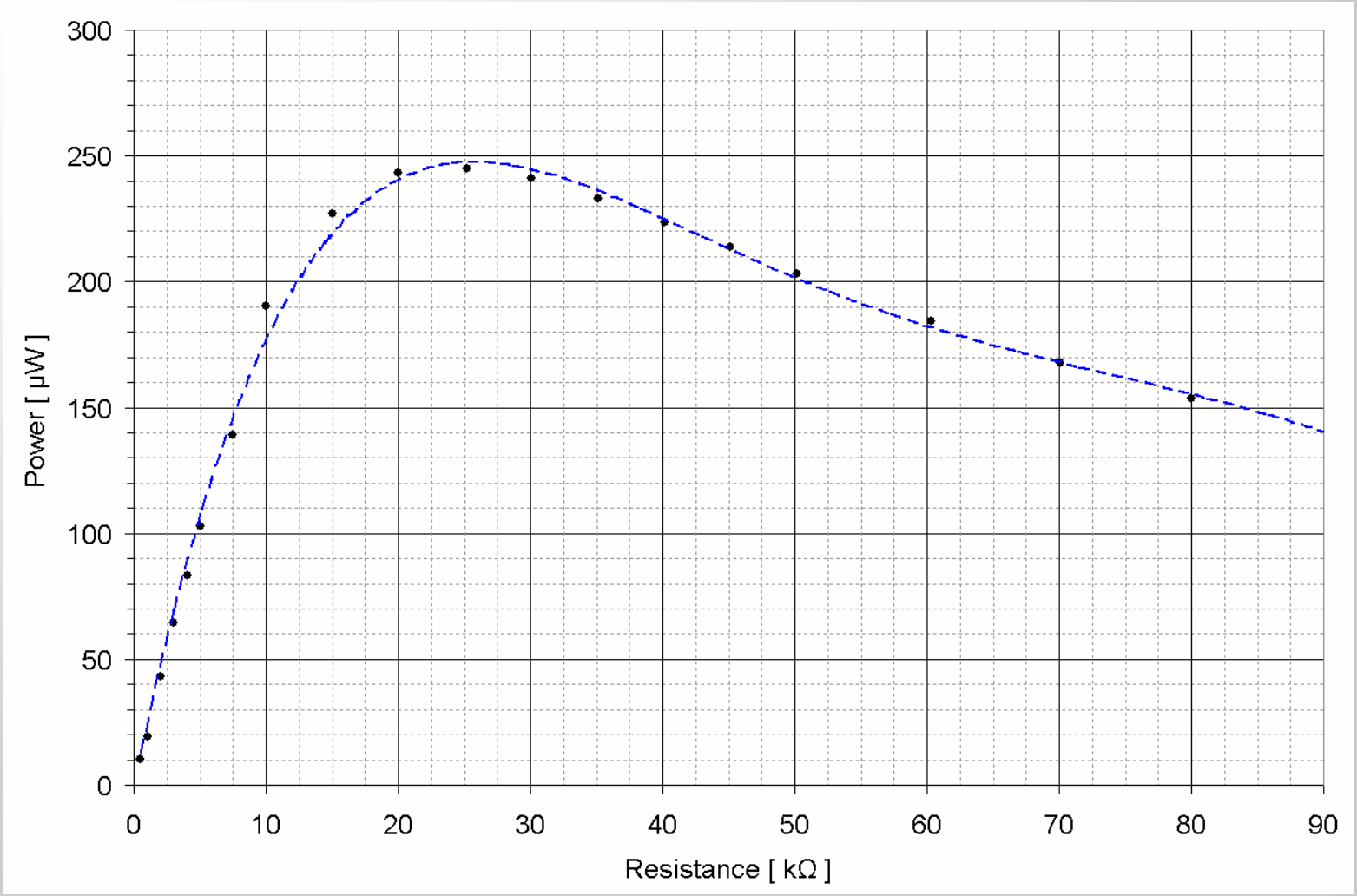
Impedance-matching shows optimal PZT loading



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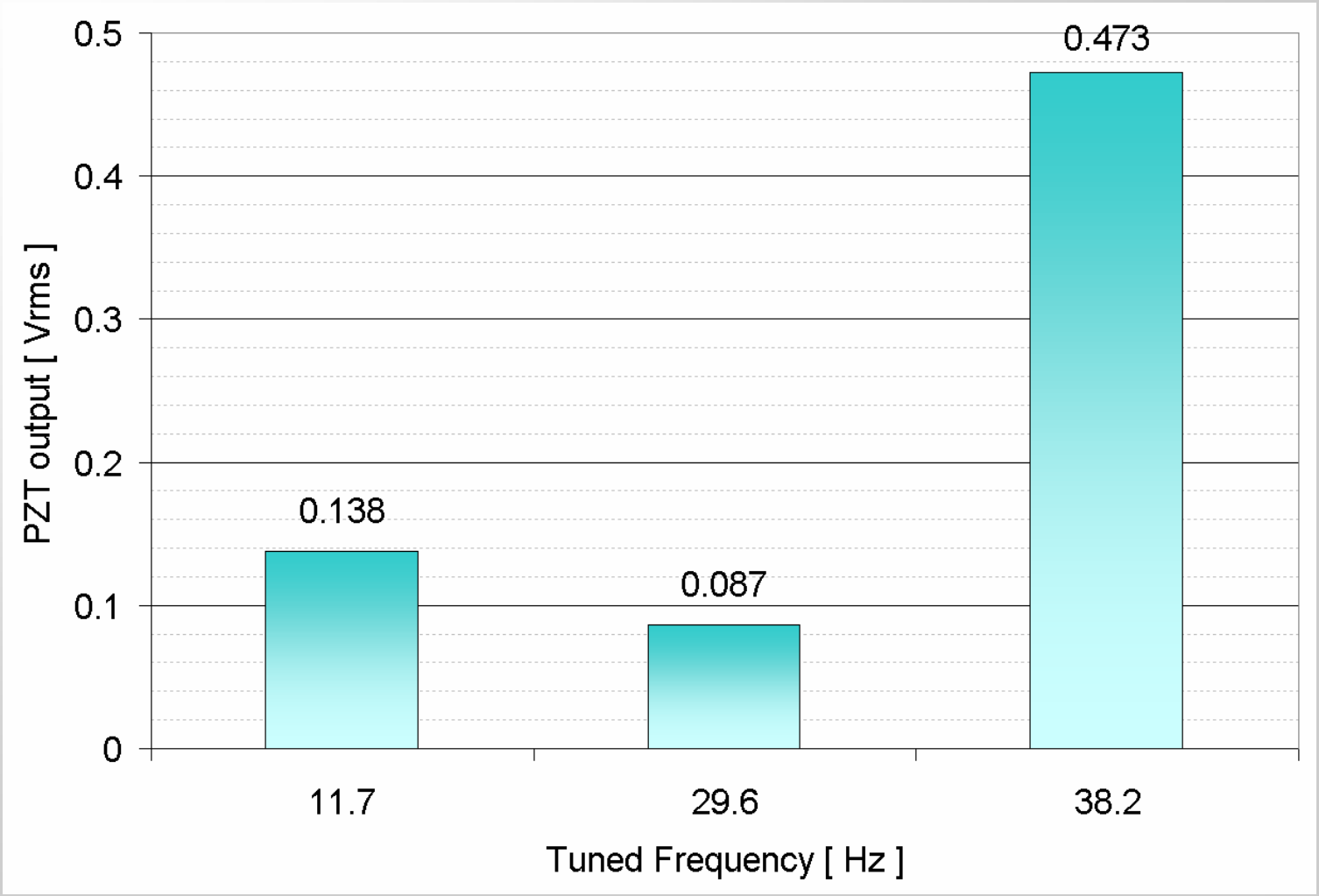
FRFs of large magnitudes increase auxiliary structure efficiency



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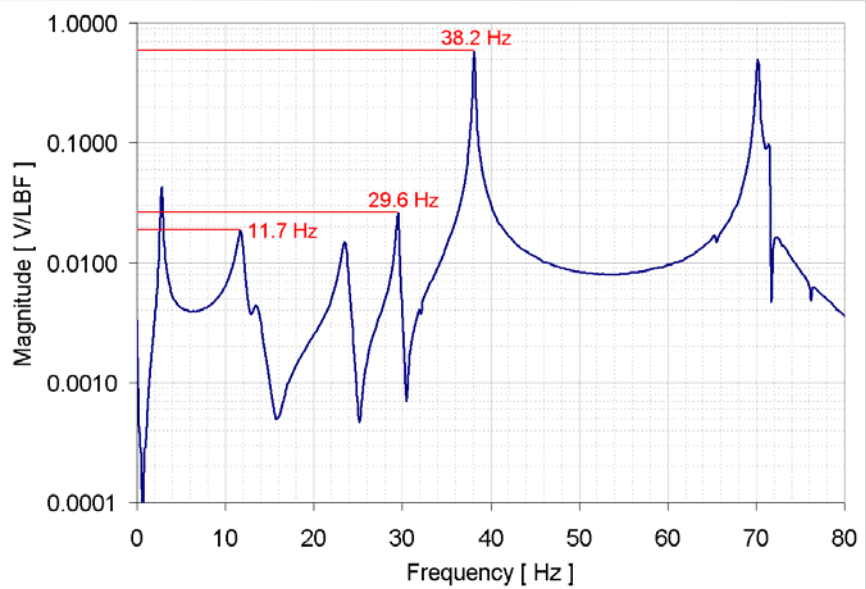
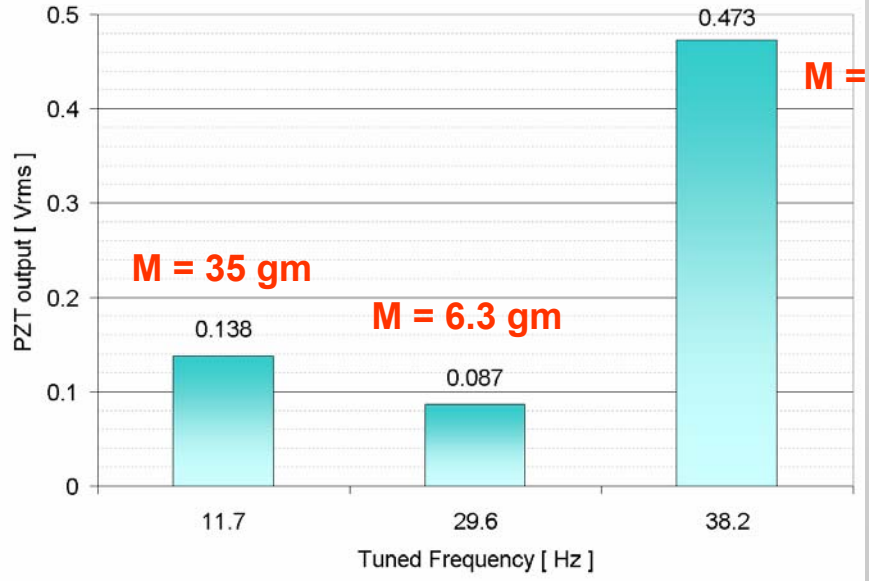
FRFs of large magnitudes increase auxiliary structure efficiency





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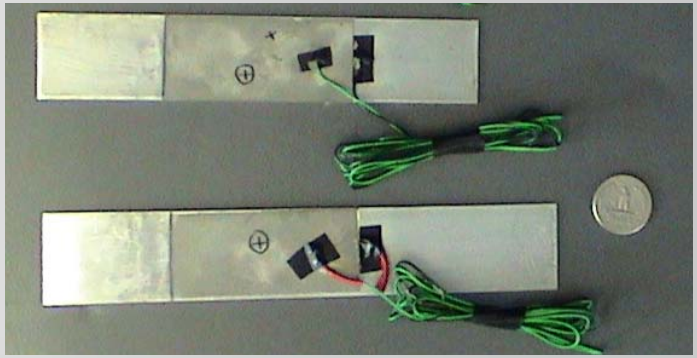
Enhanced power harvesting can be achieved using a tuned auxiliary structure

- Even mistuned auxiliary structures are beneficial
- Important parameters
  - Magnitude of mode shape at auxiliary structure's location
- Considerations for other applications
  - Time invariance
  - Input force characteristics
  - Auxiliary structure geometric constraints

Recommendations

- Single variable analysis of auxiliary structures
  - Length
  - Thickness
- PZT patch size
- Multiple PZT patches
  - In parallel (increase current)
  - In series (increase voltage output)
- Circuit optimization



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Acknowledgements

- Vibrant Technologies
  - MEScopeVES experimental modal analysis software
- The Mathworks, Inc.
  - MATLAB numerical analysis software
- Hibbitt, Karlsson and Sorensen, Inc.
  - ABAQUS finite element software

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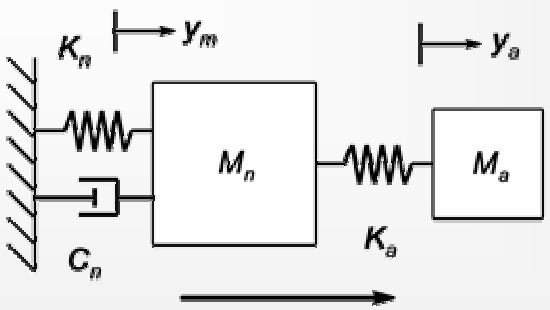

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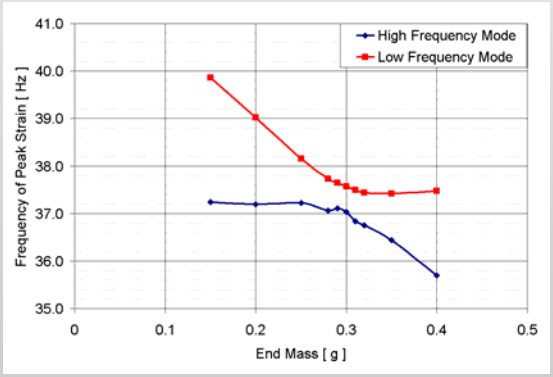
Questions?



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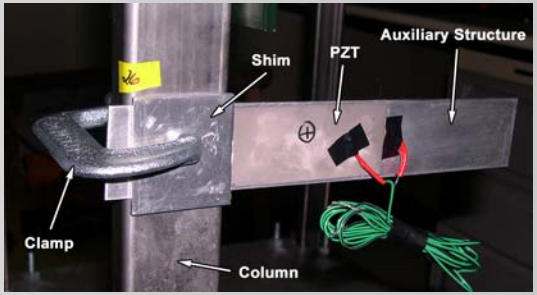

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